THE ASEAN JOURNAL OF RADIOLOGY
ISSN 2672-9393

ASEAN Movement in Radiology

DRL as a common language in patient dose reduction and optimization: A short note from AsiaSafe in 2024 RCRT-RST Annual Congress, Bangkok, Thailand

Received 23 April 2024; accepted 23 April 2024
doi:10.46475/asean-jr.v25i1.907

Nucharin Supakul, M.D.[(1)]
Kwan Hoong Ng, Ph.D.[(2)]
Seung Eun Jung, M.D., Ph. D.[(3)]
Hui-Yu Tsai, Ph.D.[(4),(5)]
Panruethai Trinavarat, M.D.[(6),(7)]
From [(1)]Indiana University School of Medicine, USA,
[(2)]College of Radiology, Academy of Medicine of Malaysia,
[(3)]Korean Society of Radiology,
[(4)]Taiwan Radiological Society,
[(5)]Chinese Society of Medical Physics,
[(6)]Royal College of Radiology of Thailand,
[(7)]Radiological Society of Thailand.
Address correspondence to N.S.(e-mail: tsupakul@iu.edu, nuchainsupakul@gmail.com)

Abstract

The AsiaSafe Asian Oceanian Symposium at the 2024 RCRT-RST Annual Congress discussed the situation and the role of radiology in patient dose reduction and optimization using Diagnostic Reference Levels (DRLs) as a common language. The scientific committee of the Royal College of Radiologists of Thailand (RCRT) and Radiological Society of Thailand (RST) established the Collaboration Symposia to discuss hot health-related topics with participating Asian Radiological societies. At the 2024 RCRT-RST Collaboration Symposia, different views, initiatives, and ideas were presented by representatives from societies.

Keywords: AsiaSafe, ALARA, Diagnostic Reference Levels (DRLs), Dose reduction, Medical physicist, Optimization, Radiation, Radiation safety, Radiologist, technologist.

Main messages

- Diagnostic reference levels (DRLs) can be adopted as a common language in promoting optimization as well as a practical tool and general guideline for clinical operations,
- DRLs was first proposed in 1990 by the International Commission on Radiological Protection (ICRP), typically set at the 75th percentile of the dose distribution from a survey conducted across a wide user base,
- DRLs is typically used for identifying situations where the levels of patient dose are unusually high,
- DRLs are not for regulatory or commercial purposes, not a dose restraint and not linked to limits or constrants,
- It is essential to ensure that the image quality appropirate for the diagnostic purpose is achieved when changing patient doses and the optimization must balance the image quality and the patient dose,
- Establishing the national DRL is somewhat chanllenging and needs to adapt to fit the situation in each country.
- Several countries in Asean Oceanian region have been embarking on various stages of DRLs development and implementation.

THE ASEAN JOURNAL OF RADIOLOGY
ISSN 2672-9393

Introduction

The Asian Symposia were established by the Royal College of Radiologists of Thailand (RCRT) and Radiological Society of Thailand (RST) scientific committee with the aim to discuss currently hot health-related topics of Asian Oceanian countries. The symposia were held in the second day of 2024 RCRT-RST and participation was by invitation only (Figure 1). The proposed topics discussed in the 2024 RCRT-RST Asian Symposia were hepatocellular carcinoma, cholangiocarcinoma, prostate cancer, and diagnostic reference level (DRL).

The following societies delivered a presentation and subsequently submitted a written report summarizing the point of view of their respective country or region. The societies included the College of Radiology, Academy of Medicine of Malaysia (MCoR), the Korean Society of Radiology (KSR), the Taiwan Radiological Society (TRS), and the Royal College of Radiologists of Thailand (RCRT) – Radiological Society of Thailand (RST).

Figure 1. *The authors and some participants from organizations related to radiation safety in Asian Symposia during the RCRT-RST annual meeting on 9 February 2024 in Bangkok, Thailand.*

The Asian Symposia were established by the Royal College of Radiologists of Thailand (RCRT) and Radiological Society of Thailand (RST) scientific committee with the aim to discuss currently hot health-related topics of Asian Oceanian countries. The symposia were held in the second day of 2024 RCRT-RST and participation was by invitation only (Figure 1). The proposed topics discussed in the 2024 RCRT-RST Asian Symposia were hepatocellular carcinoma, cholangiocarcinoma, prostate cancer, and diagnostic reference level (DRL).

The following societies delivered a presentation and subsequently submitted a written report summarizing the point of view of their respective country or region. The societies included the College of Radiology, Academy of Medicine of Malaysia (MCoR), the Korean Society of Radiology (KSR), the Taiwan Radiological Society (TRS), and the Royal College of Radiologists of Thailand (RCRT) – Radiological Society of Thailand (RST).

The Situation in Malaysia

Emeritus Professor Kwan Hoong Ng, AsiaSafe chairman and representative of the College of Radiology, Academy of Medicine of Malaysia

With a recorded population of 34.3 million in 2023, Malaysia can be considered a relatively small country in Southeast Asia after Singapore with a middle- to high-income status. Its doctor to people ratio is 2.3 per 1,000 people (The World Bank, 2023) and the nation's healthcare system has been upgraded from Healthcare Level (HCL) 2 to HCL 1 by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2022. In the field of radiology and nuclear medicine, the country has approximately 650 serving radiologists, or 0.01 radiologists for every 1,000 people, which is still a rather small figure compared with Australia and Europe (UNSCEAR 2022).

The Malaysian public healthcare system comprises a comprehensive network of clinics, hospitals and preventive health centres. According to the 2019 National Radiological Services Operational Policy published by the Medical Development

Division of the Health Ministry (MoH), radiological services have been made available at all general hospitals nationwide. Additionally, these services are also extended to 27 private specialist hospitals, 28 specialist clinics and 219 government health clinics (MoH, 2019).

As radiology grows and more patients are being subjected to procedures such as X-ray, computed tomography, positron emission tomography and magnetic resonance imaging, the MoH has commissioned three national medical radiation exposure surveys to determine patient dosimetry in hospitals nationwide. Although technology and equipment have evolved to become safer and more efficient, concerns have been raised on what constituted a safe quantity of radiation exposure, with calls for standards and guidelines to be introduced to ensure the safety of patients and medical staff.

Therefore, in the past 30 years, MoH has conducted three National Medical Radiation Exposure Surveys to monitor trends in radiological practises and to update guidelines and safety measures to suit current demands and technological advances.

1st National Medical Radiation Exposure Survey (1993-1995)

The initial national dose survey reports for diagnostic radiology practices in Malaysia spanning from 1990 to 1994 had been presented in three publications [1-3]. These findings were subsequently incorporated into the UNSCEAR 2000 report. The surveys served as foundational benchmarks, facilitating the assessment of usage patterns, trends, standards and the overall clinical service status of radiological treatments in Malaysia.

The survey results were also used to support improvements and updates in Malaysia's Quality Assurance Programme (QAP) in diagnostic radiology. The QAP in diagnostic radiology was first established in 1985, starting with 14 state hospitals and two district hospitals. By 1989, all government hospitals had implemented the QAP in their radiology departments. Subsequently, QAP was introduced to the private hospitals.

2nd National Medical Radiation Exposure Survey (2007-2009)
The MOH carried out a second medical radiation exposure survey involving both public and private healthcare institutions from 2007 to 2009 to develop diagnostic reference levels (DRLs) in diagnostic radiology, dental radiology and nuclear medicine. Data collected were also shared with UNSCEAR. The survey resulted in several publications to address quality and safety issues of radiological services in Malaysia within the period.

Additionally, guidelines for establishing national DRLs in both radiology and nuclear medicine were formulated in 2013. The 2nd National Dose Survey Report was published by MoH in 2008 (https://inis.iaea.org/collection/NCLCollectionStore/_Public/45/099/45099981.pdf). In May 2013, the national DRL on radiology and nuclear medicine was officially released by the ministry (URL).

3rd National Medical Radiation Exposure Survey (2022-2024)
The third survey is currently ongoing and has three objectives: (i) To conduct a more comprehensive national dose survey; (ii) to update DRLs in diagnostic radiology, dental radiology and diagnostic nuclear medicine; and, (iii) to include new modalities and hybrid modalities.

Research and Development in Medical Radiation Exposure/ Patient Dosimetry
There are studies carried out by local higher-learning institutions, notably Universiti Malaya(UM), Universiti Putra Malaysia (UPM), Universiti Kebangsaan Malaysia (UKM), Universiti Sains Malaysia (USM), etc. These public universities have the academic experts who have been actively collaborating with the MoH and various hospital managements, as well as related government agencies. Some recent publications include patient doses in mammography, CT, paediatric, etc. [4-9].

Additionally, two related edited books were published during this period: *"Subject Dose in Radiological Imaging.*" Ed. K-H Ng, D A Bradley and H M Warren-Forward, Elsevier 1998, and "Radiological Safety and Quality: Paradigms in Leadership and Innovation" Ed. L Lau and K H Ng, Springer 2013. These books

are the products of a unique collaboration by experts from leading international, regional and national agencies and professional organizations discussing radiation doses in imaging and promoting judicious uses to maximize the benefits and minimize the risks when using radiation in medicine.

Current and Planned Activities

Some 30 years ago, dose measurements were performed in common radiographic examinations and medical radiation exposure was surveyed only at selected radiology centres. Today, they have been expanded to include all imaging modalities and procedures at all healthcare institutions nationwide. Ongoing initiatives are conducted to raise awareness and encourage participation from multiple stakeholders. The objective is to integrate DRLs into the whole optimisation process.

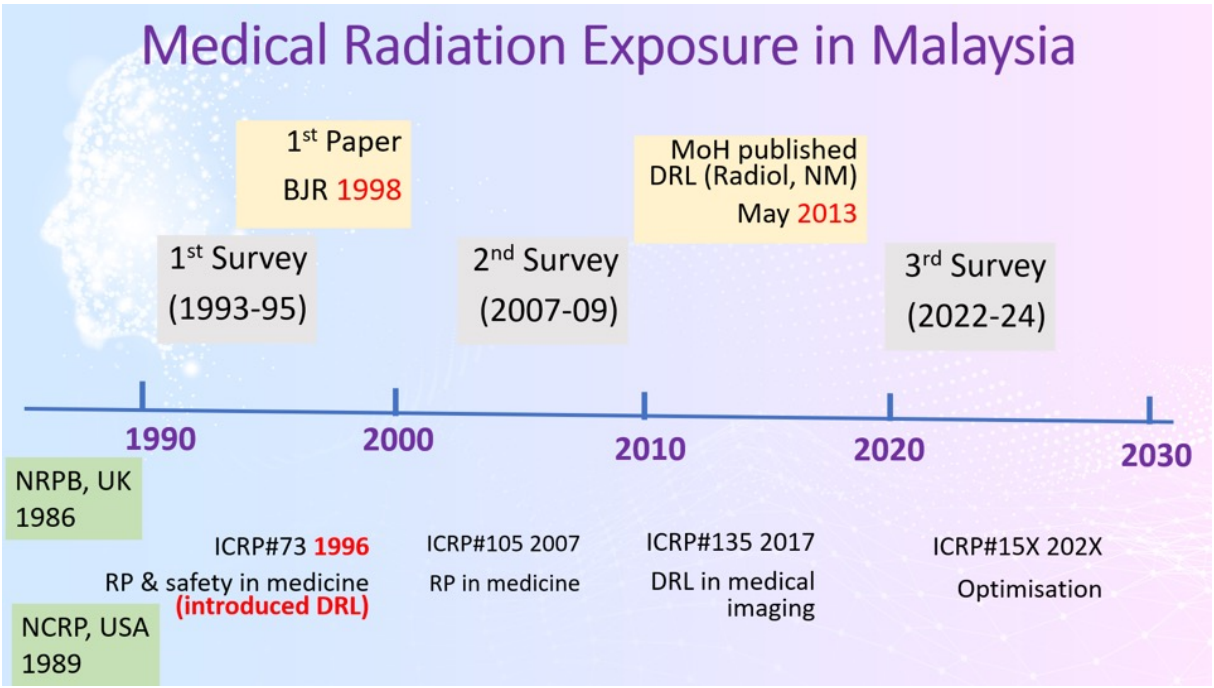

Figure 2. *Timeline of medical radiation exposure milestones in Malaysia, along with several international key developments.*

The Situation in South Korea

Professor Seung Eun Jung, representing the Korean Society of Radiology (KCR)

Since 2007, South Korea has embarked on a comprehensive initiative to establish and periodically update Diagnostic Reference Levels (DRLs) for radiographic procedures, a government-led project spearheaded by the Korean Society of Radiology (KSR). This project started with mammography and general radiography and expanded to include CT, fluoroscopy, and interventional procedures. DRLs were published for chest postero-anterior scanning and mammography in 2008, for CT scanning in 2009, for paediatric chest radiography in 2010, for general radiography in 2012, and for dental imaging in 2013 [10].

Regular updates to the DRLs were recognized as essential for reducing patient doses. These updates consider technological advancements and evolving clinical practices with a shift from initial phantom measurements to analyzing CT dose reports for contemporary data collection.

In mammography, for instance, the average glandular dose observed was 1.36 mGy in 2007, which slightly increased to 1.6 mGy in 2018 with the introduction of Digital Radiography (DR) and subsequently decreased to 1.56 mGy in 2022. Similar systematic updates to DRLs for general radiography were implemented in 2022, incorporating data from numerous medical institutions [11].

For CT scans, the methodology has been refined over the years, starting from measurements using phantoms on 2007 to including various protocols and dose report collection on 2017 and 2021. By 2021, a total of 7829 CT examinations from 225 CT scanners had been analyzed [12], providing benchmarks for patient safety and guiding dose optimization.

The 2021 survey revealed a slight increase in DRLs for some protocols compared to 2017, likely due to the inclusion of more institutions. This finding underscores the need for continued vigilance in monitoring DRLs.

THE ASEAN JOURNAL OF RADIOLOGY
ISSN 2672-9393

In terms of interventional procedures, Korea's DRLs, based on data collection of DAP and fluoroscopic time for various procedures, were lower than the average and tended to be lower than those of other nations [13].

Emphasizing pediatric radiography, data from seven university hospitals were analyzed using automated dose management software to optimize radiation doses in pediatric CT scans. The importance of continuous updates to DRLs was underscored, advocating for further research and data collection to develop national DRLs [14].

Moving toward the future, Korea is integrating advanced electronic systems for better dose monitoring and management, such as the Korean National CT Dose Index Registry (KNCDR) (Fig 1), which is currently in the pilot phase [15]. This transition to automated recording and analysis aims to enhance the effectiveness of DRLs and expand their scope to include more imaging modalities and procedures, aligning with technological advancements.

Conclusion:
South Korea's commitment to updating DRLs and integrating advanced electronic systems for radiation dose management represents a significant step forward in promoting patient safety and adapting to technological advances in medical imaging. Sustained efforts and meticulous attention to systematic DRL updates are paramount to maintaining progress and effectiveness in optimizing radiographic practices.

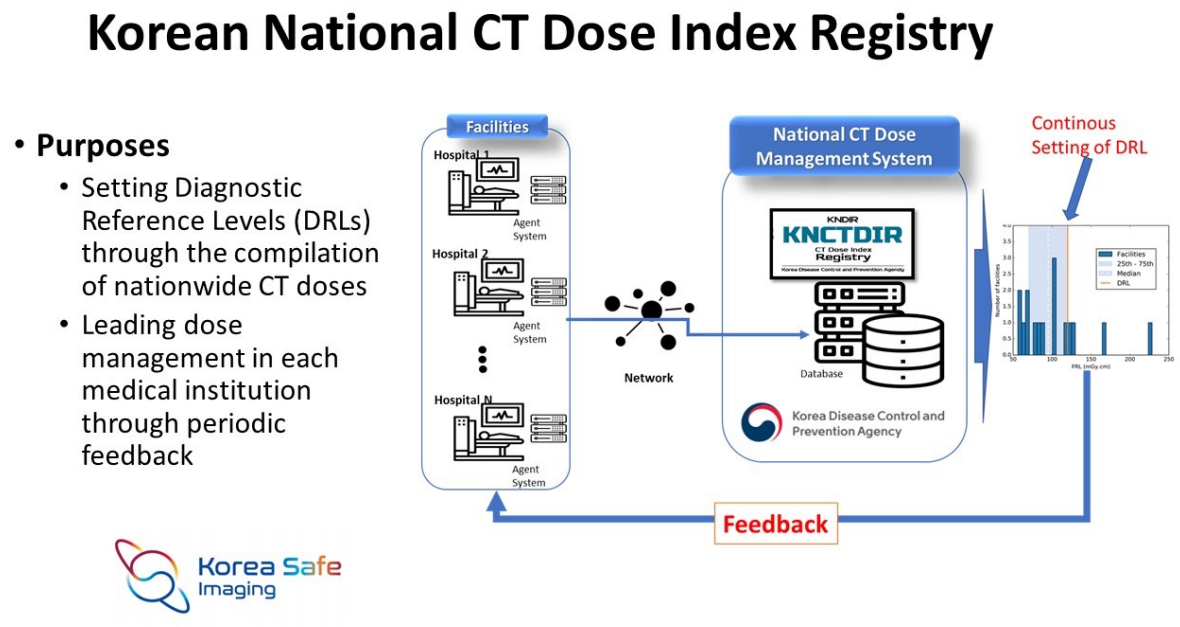

Figure 3. *An infographic showcasing the Korean National CT Dose Index Registry system: the flow diagram highlights the registry's purposes such as setting DRLs through the aggregation of nationwide CT dose data and enhancing dose management at medical institutions via regular feedback. The process involves data collection from various hospitals through an agent system, followed by analysis in a central database managed by the Korea Disease Control and Prevention Agency. The right side illustrates the continuous setting of DRL with a bar chart comparing individual facility doses against the 25th, 50th (median), and 75th percentiles, and the established DRL.*

THE ASEAN JOURNAL OF RADIOLOGY
ISSN 2672-9393

The Situation in Taiwan

Professor Hui-Yu Tsai, representing Taiwan Radiological Society (TRS), Chinese Society of Medical Physics, Taipei

Taiwan's progressive approach in radiological safety and dose optimization through the adoption of Diagnostic Reference Levels (DRLs). This initiative represents a concerted effort between key regulatory bodies—specifically, the Nuclear Safety Commission and the Ministry of Health and Welfare—and professional organizations including the Taiwan Radiological Society (TRS), the Chinese Society of Medical Physicists in Taipei (CSMPT), and the Taiwan Society of Radiological Technologists (TWSRT). This collaboration underscores Taiwan's commitment to aligning with the recommendations offered by the International Commission on Radiological Protection (ICRP).

The path to improved radiation safety began with extensive quality assurance reviews across a spectrum of radiological modalities between 2008 and 2023. These efforts laid the groundwork for the creation of both local and national DRLs, marking a pivotal advancement in reducing patient exposure during mammography, computed tomography (CT), and angio-fluoroscopy. Central to this progress has been the meticulous collection of radiological data, which includes a broad range of dose metrics such as average glandular dose (AGD), volumetric CT dose index (CTDIvol), dose length product (DLP), and incident air kerma rate at the patient entrance reference point (Ka,r). This data compilation has been crucial in establishing National Diagnostic Reference Levels (NDRLs) [16-19], setting a new standard for radiological procedures throughout the country.

To facilitate the widespread adoption and effective implementation of DRLs, Taiwan has initiated several guidance [20-23] and education programs. These encompass developing standardized operating procedures, fostering hospital collaborations, and conducting expert-led seminars and workshops. Aimed at cultivating a culture of ongoing improvement, these initiatives strive to integrate DRL principles into the core practices of Taiwan's radiological sector, emphasizing their essential role in optimizing patient safety and enhancing the quality of medical imaging practices.

Looking forward, Taiwan is committed to expanding the scope of NDRLs to include a broader array of CT scans and mammography, adapting to diverse breast sizes and 3D scans. This diligent endeavor underscores the importance of regular data evaluations to align with evolving safety standards, thus emphasizing the universal significance of DRLs in advancing medical imaging safety and efficacy. Taiwan's proactive measures underscore a long-term commitment to elevating radiological standards, spotlighting the necessity of continuous education and quality enhancement in radiological safety.

Conclusion:

Taiwan's strategic deployment of DRLs represents a crucial step forward in enhancing radiological safety and optimizing dose management. Collaborative efforts among government regulators and professional organizations have cultivated a comprehensive framework for reducing radiation exposure in diagnostic procedures. The diligent gathering and analysis of radiological data have been instrumental in establishing National DRLs, guiding medical imaging practices toward heightened safety and efficiency. Through the ongoing expansion of these standards and a strong focus on education and quality improvement, Taiwan actively contributes to the global mission of improving radiological health and safety, highlighting the indispensable role of DRLs in fostering superior patient care and advocating for continuous progress in the radiological sciences.

THE ASEAN JOURNAL OF RADIOLOGY
ISSN 2672-9393

The Situation in Thailand

Associate Professor Panruethai Trinavarat, representing the Royal College of Radiology of Thailand and Radiological Society of Thailand

The establishment of national DRLs in Thailand was first started by the Department of Medical Sciences, Ministry of Public Health (DMSc, MoPH) for general and dental radiographs in the fiscal year 2017. Before 2017, a patient dose in Thailand was already an issue of concern and had been surveyed in several medical schools, but mostly in a single center or in a small group of hospitals, for the high dose imaging - particular CT scanning and interventional radiology [24-30]. In the year 2018, there were two coincidental projects to survey patient doses in CT, one by the DMSc, and the other by a group of radiologists from medical schools under the country project THA 6043 supported by the International Atomic Energy Agency (IAEA). The ICRP publication 135 has been used as the guideline and there were renowned medical physicists from IAEA Expert Mission visiting Thailand to enlighten the DRL process and also dose management.

Since 2018, there has been a mutual agreement that the establishment of DRLs in Thailand would be mainly conducted by the DMSc with the collaboration of medical schools and/or professional organizations to have radiologists, radiologic technologists, and medical physicists involved in the DRL process, because some imaging procedures and/or patients are somehow complicated and clinical subspecialties can help clarify the imaging process and suggest how to fill the dose record forms.

Thai DRLs of mammography were established in 2019 and the DRLs of interventional neuroradiology and body interventional radiology procedures were established in 2020 with the collaboration between the DMSc, medical schools and the Thai Society of Vascular and Interventional Radiology (TSVIR). Since 2021, the DMSc started the second round of DRL process.

To broaden national and local DRLs to include more imaging modalities and more imaging procedures, several professional organizations created their own surveys on imaging not having been surveyed by the DMSc. These included DRLs in Nuclear Scintigraphs, Cardiac IR procedures, CT angiography in several areas, head CT in pediatrics, and more. The DRL results from these surveys have been collected and reported together in the published National Diagnostic Reference Levels in Thailand (updated 2023) by the DMSc, and can be accessed online from the website of the Royal College of Radiologists of Thailand (RCRT) [31], however, in a Thai version.

Besides the manual national and local surveys for DRL establishment, Thailand has started dose registry for CT by using dose monitoring software, initiated by the country project THA6043 supported by the IAEA. There was a meeting among (expecting) participating hospitals to set an agreement on which CT procedures were common and should have DRLs. This CT dose registry started its function on January 2022, collecting dose data of 14 CT protocol names from 9 participating hospitals with the central server at the Office of Atoms for Peace (OAP) who runs the project in collaboration with the RCRT. Each participating hospital has got feedback every trimester of the hospital's median CT dose compared to DRLs of the group. The hospital(s) using significantly a high CT dose was directedly contacted, and the expert team from the RCRT could provide the online consultance or even a site visit to help them in optimization. The local DRLs of Thai CT dose registry can also be accessed online from the website of the Royal College of Radiologists of Thailand (RCRT) in a Thai version [32]. The number of participating hospitals will expand from 9 hospitals to 17 hospitals in 2024, and 27 hospitals in 2025.

The establishment of pediatric DRLs in Thailand is a big challenge, as the number of examinations is quite small relative to the number of the exams in adults, and has to be further categorized with age bands. Although Thai local DRLs for pediatrics can be established in some modalities and some procedures, they are still incomplete and some are partly dominated by data from university hospitals.

THE ASEAN JOURNAL OF RADIOLOGY
ISSN 2672-9393

The result of Thai DRLs shows that most of the imaging modalities and procedures providing a radiation dose not much different from those reported from other countries, but Thailand still has ample opportunities for improvement. There is evidence from the first and second rounds of DRL establishment for general radiographs that there has been obvious dose rising in chest X-ray from digital radiography. Other concerning findings are the relatively high Thai DRLs for adult chest CT and adult abdomen-pelvis CT from the national survey, and the high DRLs for pediatric head CT from Thai CT dose registry. Thailand has been trying to solve these problems through education- to both radiologic technologists and radiologists, both in the curriculum and in continuous medical education. Initiation of the audit system on patient dose has been raised, but not yet fixed.

Acknowledgements

This paper was prepared by Associate Professor Nucharin Supakul, Chairperson of the AsiaSafe Asian Oceanian Symposia, with the support of Associate Professor Wiwatana Tanomkiat, Chairperson of the Ceremonies and Hostesses of RCRT-RST 2024 and Editor in Chief, ASEAN Journal of Radiology, on the basis of the reports and presentations delivered at the symposia by

1. Professor Kwan Hoong Ng, representing Chairperson of AsiaSafe and the College of Radiology, Academy of Medicine of Malaysia,
2. Professor Seung Eun Jung, representing the Korean Society of Radiology,
3. Professor Hui-Yu Tsai, representing the Taiwan Radiologicl Society,
4. Associate Professor Panruethai Trinavarat, representing the Royal College of Radiologists of Thailand and the Radiological Society of Thailand.

The paper was provided to the presenters for feedback. It was approved by the Associate Professor Nucharin Supakul, AsiaSafe Committee, Asian Oceanian Society of Radiology on 22 April 2024.

References

1. Ng KH, Rassiah P, Wang HB, Hambali AS, Muthuvellu P, Lee HP. Doses to patients in routine X-ray examinations in Malaysia. Br J Radiol 1998;71:654-60. doi: 10.1259/bjr.71.846.9849390.

2. Ng KH, Abdullah BJ, Rassiah P, Sivalingam S. X-ray based radiological procedures in Malaysia: 1990-1994. Med J Malaysia 1999;54:185-91.

3. Ng KH, Abdullah BJ, Sivalingam S. Medical radiation exposures for diagnostic radiology in Malaysia. Health Phys 2000; 77:33-6. doi: 10.1097/00004032-199907000-00007.

4. Jamal N, Ng KH, McLean D. A study of mean glandular dose during diagnostic mammography in Malaysia and some of the factors affecting it. Br J Radiol 2003;76:238-45. doi: 10.1259/bjr/66428508.

5. Sabarudin A, Sun Z, Ng KH. Radiation dose associated with coronary CT angiography and invasive coronary angiography: an experimental study of the effect of dose-saving strategies. Radiat Prot Dosimetry 2012 ;150:180-7. doi: 10.1093/rpd/ncr377.

6. Muhammad NA, Karim MKA, Hassan HA, Kamarudin MA, Wong JHD, Ibahim MJ. Estimation of effective dose and organ cancer risk from paediatric computed tomography thorax–abdomen-Pelvis examinations. Radiat Phys Chem 2019;165:108438.

7. Abdulkadir MK, Shuaib IL, Achuthan A, Nasirudin RA, Samsudin AHZ, Osman ND. Estimation of pediatric dose descriptors adapted to individual specific size from CT examinations. Radiat Prot Dosimetry 2022;198:1292-302. doi: 10.1093/rpd/ncac163.

8. Muhammad NA, Karim MKA, Harun HH, Rahman MAA, Azlan RNRM, Sumardi NF. The impact of tube current and iterative reconstruction algorithm on dose and image quality of infant CT head examination. Radiat Phys Chem 2022;200:110272.

9. Jusoh II, Abdullah KA, Ali MH. Diagnostic reference levels for common CT examinations: results from a statewide dose survey. Radiat Prot Dosimetry 2022;198:1417-23. doi: 10.1093/rpd/ncac182.

10. Do KH, Jung SE. Current status of medical radiation exposure in Korea - recent efforts to develop a radiation exposure control system focussed on justification and optimisation. Ann ICRP 2016;45(1 Suppl):113-21. doi: 10.1177/0146645316637783.

11. Yoon Y, Park H, Won J, Song S, Gil, J, Lee BY. Korean diagnostic reference level for general radiography and mammography in 2022. Public Health Wkly Rep [Internet]. 2023 [cited 2024 Apr 14];16:1082-100. Available from: https://www.researchgate.net/publication/373019541_Korean_Diagnostic_Reference_Level_for_General_Radiography_and_Mammography_in_2022.

12. Nam S, Park H, Kwon S, Cho PK, Yoon Y, Yoon SW, et al. Updated national diagnostic reference levels and achievable doses for CT protocols: a national survey of Korean hospitals. Tomography 2022; 8: 2450–59. doi: 10.3390/tomography8050203.

13. Lee MY, Kwon J, Ryu GW, Kim KH, Nam HW, Kim KP. Review of National diagnostic reference levels for interventional procedures. Prog Med Phys 2019;30:75-88. doi.org/10.14316/pmp.2019.30.4.75

14. Hwang JY, Choi YH, Yoon HM, Ryu YJ, Shin HJ, Kim HG, et al. Establishment of local diagnostic reference levels of pediatric abdominopelvic and chest CT examinations based on the body weight and size in Korea. Korean J Radiol 2021;22:1172-84. doi: 10.3348/kjr.2020.0890.

15. Kim JS, Kwon SM, Cho PK, Yoon SW, Kim JH, Gil JW, et al. Policy planning for patient dose registry system for computed tomography examination. Public Health Wkly Report 2022;15(16):1057-68.

16. Lin YY, Tsai HY, Wu YE, Liao YL, Hwang YS. A nationwide survey on the dose of digital breast tomosynthesis. Formosan J Med 2019;23:289–309. doi: 10.6320/fjm.201905_23(3).0002.
17. Tung CJ, Tsai HY, Lo SH, Guan CN, Chen YB. Determination of guidance levels of dose for diagnostic radiography in Taiwan. Med Phys 2001;28:850–7. doi: 10.1118/1.1368126.

18. Hwang YS, Chen CC, Liao YP, Kuang WC, Tsai HY, Liu HL. Establishment and application of diagnostic reference levels of medical radiation exposures. Formosan J Med [Internet]. 2012 [cited 2024 Apr 14];16:518–28. Available from:https://www.airitilibrary.com/Article/Detail/10281916-201209-201210300009-201210300009-518-528.

19. Tsai HY, Tung CJ, Yu CC, Tyan YS. Survey of computed tomography scanners in Taiwan: dose descriptors, dose guidance levels, and effective doses. Med Phys 2007;34:1234–43. doi: 10.1118/1.2712412.

20. Hwang YS, Yeh MY, Chiang SW, Liu IC, Liao YL, Tsai HY, et al. Recommendations for physics testing of digital mammography systems. Formosan J Med [Internet]. 2018 [cited 2024 Apr 14];22:311–23. Available from: https://www.airitilibrary.com/Article/Detail?DocID=10281916-201805-201805310001-201805310001-311-323.

21. Hwang YS, Hsiao YH, Chiang SW, Yeh MY, Liu IC, Yan FX, et al. Recommendations for physics testing of fluoroscopic and interventional radiologic systems. Formosan J Med [Internet]. 2015 [cited 2024 Apr 14];19:517–27. Available from: https://www.airitilibrary.com/Article/Detail/10281916-201509-201510050023-201510050023-517-527.

22. Tsai HY, Chen CC, Hwang YS, Liu HL. Review and recommendations for physics testing of x-ray computed tomography: CSMPT CT task group report. Chin J Radiol [Internet]. 2009 [cited 2024 Apr 14];34:173–84. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-76149086157&partnerID=40&md5=394ce7e889baa076403e41173bcf128d. Subscription required.

23. Hwang YS, Wang H, Chen C, Liu H, Tsai HY. Review and recommendations for physics testing of conventional and digital mammography: CSMPT mammography task group report. Chin J Radiol [Internet]. 2008 [cited 2024 Apr 14];33:153–79. Available from:https://www.airitilibrary.com/Article/Detail?DocID=10188940-200809-33-3-153-179-a

24. Wongsanon S, Witchathorntakun W, Wongsanon W. Patient radiation dose received from the body interventional radiology. Srinagarind Med J 2009; 24:339–43. Thai.

25. Trinavarat P, Kritsaneepaiboon S, Rongviriyapanich C, Visrutaratna P, Srinakarin J. Radiation dose from CT scanning: can it be reduced? Asian Biomed 2011;5 (: 13-21.

26. Trinavarat P, Manaphol S, Yimpraphan N, Assawakulkamnurd S. Cancer risk from pediatric diagnostic radiology; should we be concerned? Chula Med J 2011; 55: 621-32. Thai.

27. Urairat J, Asavaphatiboon S, Singhara Na Ayuthaya S, Pongnapang N. Evaluation of radiation dose to patients undergoing interventional radiology procedures at Ramathibodi Hospital, Thailand. Biomed Imaging Interv J 2011; 7:e22. doi: 10.2349/biij.7.3.e22.

28. Kritsaneepaiboon S, Trinavarat P, Visrutaratna P. Survey of pediatric MDCT radiation dose from university hospitals in Thailand: a preliminary for national dose survey. Acta Radiol 2012; 53:820-6. doi: 10.1258/ar.2012.110641.

29. Admontree S, Krisanchinda A, Laothamatas J, Trinavarat P. Radiation dose on whole brain computed tomography in comprehensive stroke imaging using axial volumetric 30-detector CT. Chula Med J 2015;59:1-11.

30. Sulagaesuan C, Saksobhavivat N, Asavaphatiboon S, Kaewlai R. Reducing emergency CT radiation doses with simple techniques: a quality initiative project. J Med Imaging Radiat Oncol 2016;60:23-34. doi: 10.1111/1754-9485.12410.

31. Department of Medical Sciences, Ministry of Public Health. National diagnostic reference levels in Thailand 2023. [Internet]. Nonthaburi: Ministry of Public Health; 2023 [cited 2024 Apr 14]. Availble from: https://www.rcrt.or.th/wp-content/uploads/2023/10/National-DRLs-in-Thailand-2023.pdf. Thai.

32. Office of Atoms for Peace, Royal College of Radiologists of Thailand. Thailand national CT dose registry, trimester report 2023 [Internet]. Bangkok: RCRT; 2023 [cited 2024 Apr 14]. Available from: https://www.rcrt.or.th/thailand-national-ct-dose-registry/. Thai.